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In thirty years, the Unipress research facility has notched up some impressive achievements. Building on its expertise in high pressure work, the group has concentrated on III-nitrides and in the last year has demonstrated its first blue laser diodes.

To exploit this and other technical breakthroughs, Unipress has established TopGaN – a commercial spin-off that will bring blue and uv laser diodes to the market within a year, as well as supplying III-N epitaxial structures and other technical services.

Blue lasers – the latest in 30 years of successes

How it begun...

The UNIPRESS High Pressure Research Center at the Institute of Polish Academy of Sciences, will celebrate its 30th anniversary this year. Remarkably, for all that time Unipress has been headed by Professor Sylwek Porowski. When you ask him to identify the major achievements of Unipress, he is quick to list an impressive sequence of successes:

1) Six high-tech spin-offs established

2) Patents for many unique high-pressure technologies

3) Recognition by the European Union as a Center of Excellence

4) Contribution to scientific knowledge through more than 200 invited talks and more than 2000 scientific papers.

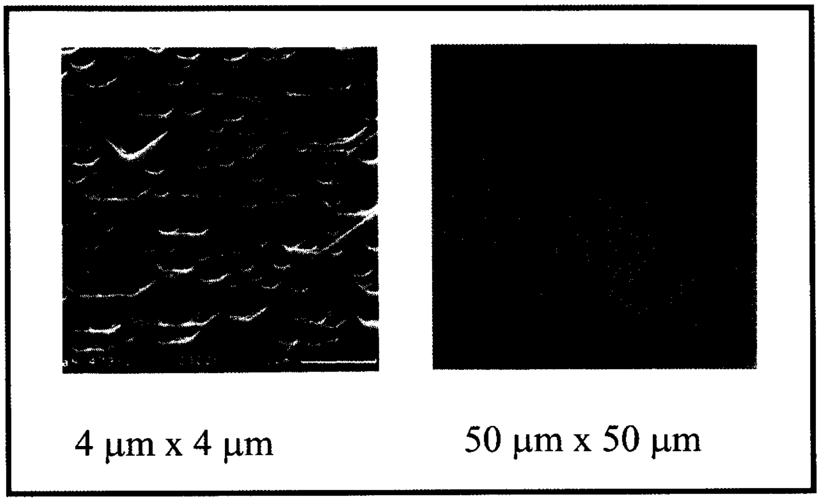

Figure 1: Etch pit density for a GaN layer on sapphire (left) and for a GaN layer on bulk GaN.

Specialization

Within Unipress, there are six labs, each with its own specialization. These are classified as follows:

1) Semiconductors

2) GaN crystallization

3) High T_c superconductors

4) Nanocrystalline materials

5) Food-preservation

6) High pressure equipment.

The first two of these labs (emplying 30 scientists) work on the properties of III-N compounds and devices.

This level of interest in nitrides at the high-pressure institute was quite natural. At 1 bar GaN decomposes at about 1000 °C. As the melting point of GaN is 2800 °C (at 45 kbar) it was clear that at low pressures, the growth of high quality crystals would be almost impossible. Therefore, Unipress started its research on nitrides almost the day after being established. The experimental results concerning Ga-N thermodynamics indicated something very important: that it should be possible to grow GaN single crystals at high nitrogen pressure within the accessible ranges of pressure (up to 20 kbar) and temperature (up to 1800 °C).

GaN single crystals

It is not easy to produce high pressure and high temperature and maintain them for a long time . It is not easy to grow any single crystal.To grow single crystals at the high pressure of 20 kbar, is a real challenge. At the beginning, the high-pressure chambers were rather small with a working volume of just a few cubic centimeters.The crystals were also rather small - less than 1 mm. But they had a very low dislocation density - less than 10^2 cm^{-2}, six orders of magnitude less than the commonly used best GaN layers on sapphire or SiC.

Figure 1 shows two topographs which compare etch pit density (EPD) for a typical GaN layer on sapphire and the GaN single crystal.

Over the last ten years, the size of the high-pressure chambers has been continuously increasing.At present, Iza Grzegory and her group are using pressure cells which have a working volume of a several litres and are growing GaN crystals up to half an inch in diameter.The next generation of these chambers should produce one-inch bulk samples.The crystals can be either highly conductive (good for LDs) due to the presence of oxygen impurities, or insulating (good for electronic devices) when they are doped with magnesium.

Basic research

Unipress' GaN crystals have been examined not only in Unipress by the group of Tadek Suski, but also in at least 20 laboratories all over the world. In this research, many material parameters of dislocation-free GaN have been measured.Amongst others, let me mention: lattice parameters, thermal expansion coefficients, bulk modulus, photoluminescence spectra (with lines as narrow as 0.1 meV), diffusion coefficients, or pressure coefficients of the band gap and dopant levels.

Epitaxy

First attempts at epitaxy on our bulk crystals were not very successful in other labs.The morphology of the layers was very bad. It was clear that we did not know how to prepare the surface for epitaxy. Four years ago, Sylwek Porowski and I made a strategic decision: epitaxy technology must be introduced to Unipress to overcome this problem.The task seemed to be very difficult, as we had no experience in any kind of epitaxy technology. Fortunately, we received significant assistance from Marek Tlaczala (Wroclaw University of Technology) and Bernard Beaumont (CRHEA-Valbonne).Very soon, the MOVPE lab, equipped with two home-made systems, begun its activity.

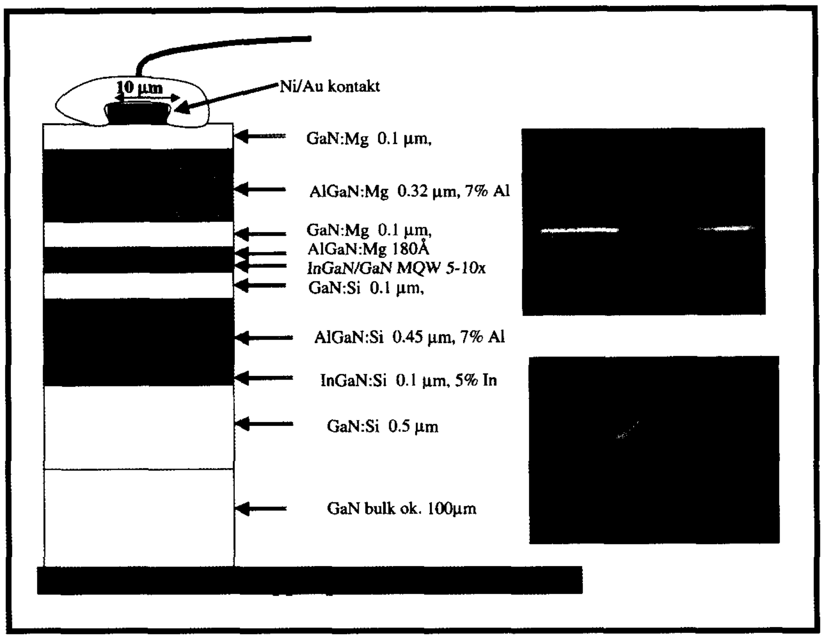

Figure 2: Blue lasers from Unipress.

It turned out that surface preparation before epitaxy was a very difficult part of the research on epitaxy using bulk GaN crystals as substrates.The subsurface layer damaged by mechanical polishing had to be removed, but the gallium face of the GaN crystals is almost chemically inert. Therefore, mechano-chemical polishing cannot be applied.We were forced to develop surface preparation technology using reactive ion etching followed by chemical treatment.

Having epi-ready substrates, Pawel Prystawko and his collegues in the MOVPE group can grow most of the useful InGaN and AlGaN layers which are atomically flat and reproduce the ultra-low dislocation density of the GaN substrates. In particular, we checked using various techniques (AFM,TEM, XRD) that our laser structures are free of any mismatch-related defects.

MOVPE technology is the most popular for nitrides, but many experimental results and predictions indicate that for the low-dislocation-density material MBE should produce some layers (for example, HEMT structures) of better quality. Therefore, just two months ago, an MBE system (Semicon V90) was installed in our epitaxy lab and the first experiments have been already performed.

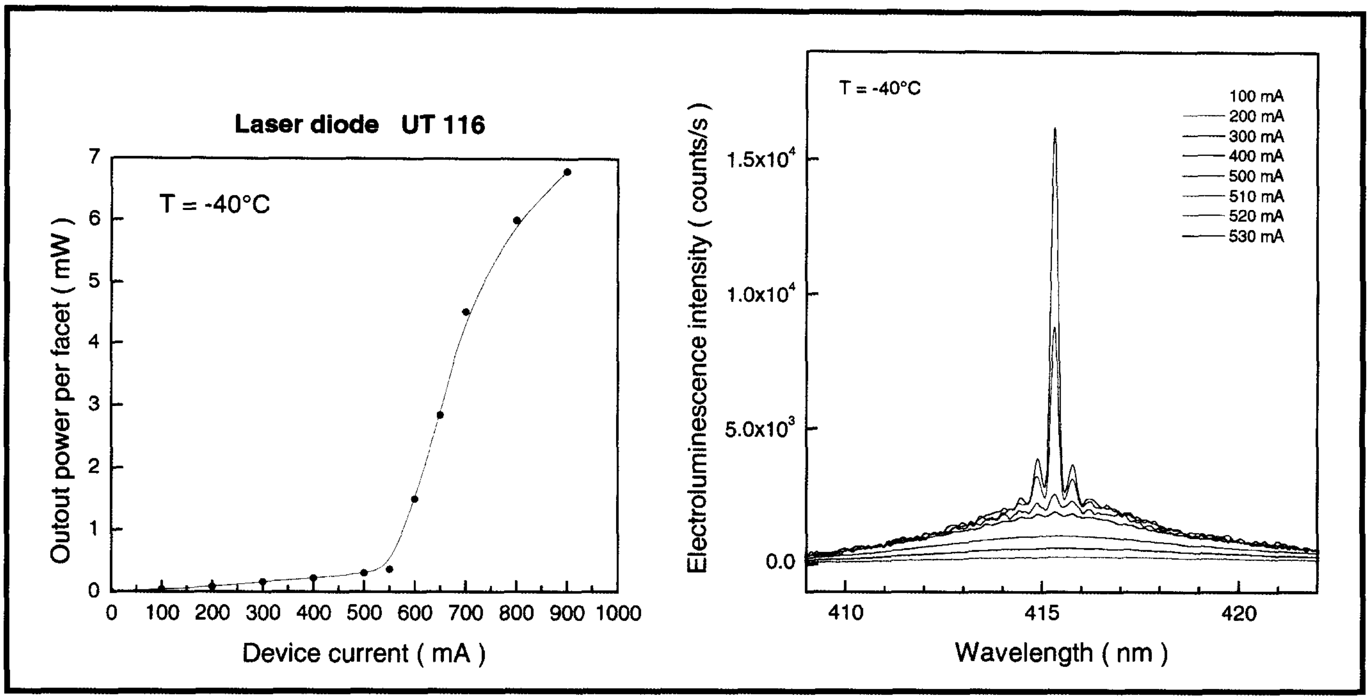

Figure 3a: Optical output power as a function of current intensity
- pulse width: 100ns
- frequency: 1 kHz.

Figure 3b: Spectra of omitted light for different current magnitude
- pulse width: 100ns
- frequency: 1 kHz.

Finances

The success of Unipress in growing GaN single crystals and epitaxy paved the way for establishing a project "Development of Blue Optoelectronics" realized by Unipress and other Polish Institutes.The project, worth US$25 m over 4 years, is financed 30% by the Polish Government (Committee of Scientific Research and Ministry of Industry) and 70% by private investors (an exceptional situation in Poland!).As a result of this project, production of the blue-optoelectronic devices is planned.

It is also important to acknowledge help from the European Union sponsoring the Center of Excellence Program and Nitrides Consulting (see http://consult.unipress.waw.pl).The latter organization supplies basic information on III-N materials and devices to research and industrial groups.

Blue laser

The laser-processing lab was created by Piotr Perlin in record time.The first piece of equipment (RIE) was installed in February 2001, the last one (RTP) in November. On 12th of December, the first Unipress blue lasers (edge emitting) were ready and successfuly tested (Fig. 2).The stripe size was 10 x 500 mm^2, the mirrors were obtained by cleaving (a big advantage over sapphire substrates) and coated by two pairs of SiO_x/ZrO_x layers.As the substrate was highly conductive, we could make the n-type contact to its reverse side. Figure 3 shows the main characteristics of the laser diode: spectrum below and above the threshold (14 kA/cm^2), as well as the power dependence on current.The lasers work in a pulse-mode (200 ns at 1kHz) at -40 - 0 °C. If all goes according to plan, cw LDs of 3-5 mW power should be demonstrated within a year.

TopGaN

TopGaN is the latest Unipress spin-off. Its task is to commercialize nitride products. It belongs to Unipress and private investors and uses an 800 m^2 clean-room facility with:

1) high-pressure equipment for bulk GaN growth and annealing
2) 2 MOVPE home-made reactors
3) MBE V90
4) laser processing equipment
5) characterization equipment.

TopGaN's main products should be blue and UV LDs.The first commercially available LDs are expected within a year. However, in parallel to laser activity,TopGaN offers III-N epitaxial structures free of mismatch-related defects, service in constructing MOVPE equipment, as well as service in high-pressure annealing up to 20 kbars and 1800 °C. Such conditions are necessary for many technological processes, for example, to remove implantation-related defects.